West Fork White River, Muncie to Hamilton-Marion County Line TMDL for *E. Coli* Bacteria

Modeling Framework Report

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1.0 INTRODUCTION

The West Fork White River (WFWR) from Muncie to the Hamilton-Marion County line drains approximately 1,100 square miles in central Indiana (Figure 1). Three segments of this stretch of the WFWR appear on Indiana's section 303(d) list of impaired waters for failing to fully support the state's recreation use (Figure 2)[1]. These impairments were identified based on data collected by the Indiana Department of Environmental Management (IDEM) during the 1996 and 2001 water quality surveys which showed violations of the *Escherichia Coli (E. Coli)* standard. *E. Coli* is a bacterium that indicates the presence of human sewage and animal manure. It can enter rivers through direct discharge from mammals and birds, from agricultural and storm runoff carrying mammal wastes (manure), and from sewage leaked into the water. *E. Coli* is also an indication of the possible presence of other disease causing organisms or pathogens.

The Clean Water Act and U.S. Environmental Protection Agency (USEPA) regulations require that states develop Total Maximum Daily Loads (TMDLs) for all waters on the section 303(d) lists. A TMDL is the sum of the allowable amount of a single pollutant that a waterbody can receive from all contributing point and nonpoint sources and still support its designated uses. IDEM is in the process of developing *E. Coli* TMDLs for the WFWR above the Hamilton-Marion County line and the overall goals and objectives of the project are to

- Further assess the water quality of the WFWR and identify key issues associated with the impairments and potential pollutant sources.
- Use the best available science to determine the maximum load of *E. Coli* that the river can receive and still fully support all of its designated uses.
- Use the best available science to determine current loads of *E. Coli*
- If current loads exceed the maximum allowable load, determine the load reduction that is needed.
- Identify feasible and cost-effective actions that can be taken to reduce loads.
- Inform and involve the public throughout the project to ensure that key concerns are addressed and the best available information is used.
- Submit a final TMDL report to USEPA for review and approval.

Previous reports have described the data available to develop the TMDL (Tetra Tech, 2002) and estimated the likely sources of *E. coli* (Tetra Tech, 2003). The purposes of this report are to:

- Describe the modeling that will be done to identify the cause and effect relationship between the sources of *E. coli* bacteria and the attainment of the water quality standards for *E. coli* bacteria.
- Describe the approach that will be taken to develop, test, and evaluate various alternatives for meeting the water quality standards. The alternatives will address the distribution of the loading capacity among wasteload allocations (WLAs), load allocations (LAs), and natural background.
- Describe the approach that will be taken to address a margin of safety and seasonal variations, as required by Section 303(d)(1)(C) of the Clean Water Act.

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[1] Indiana's current section 303(d) list is the one submitted to USEPA in 1998 and approved by USEPA in 1999. A draft 2002 section 303(d) list is currently being reviewed by USEPA.

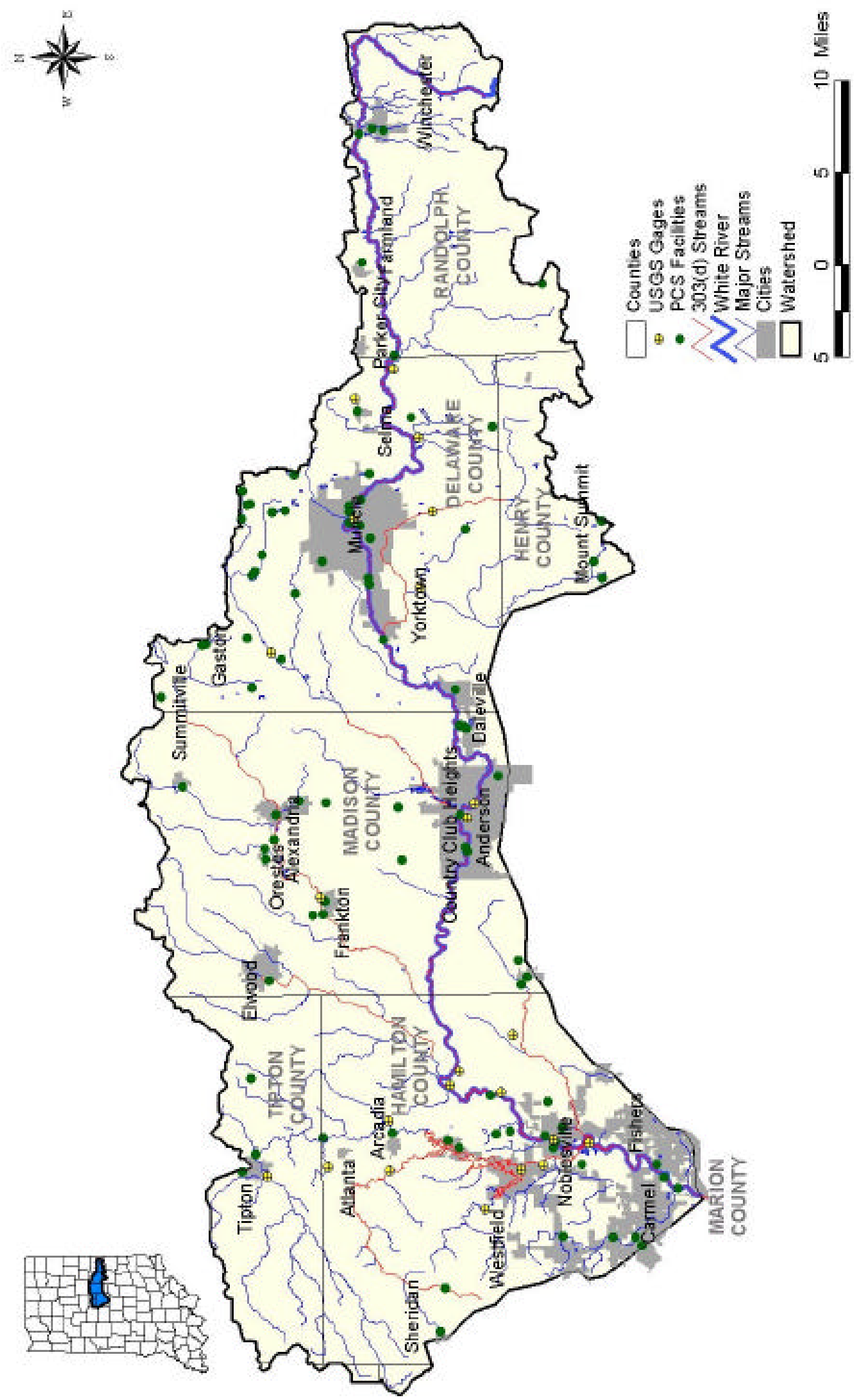


Figure 1. Political map of the WFWR watershed above the Hamilton-Marion County line.

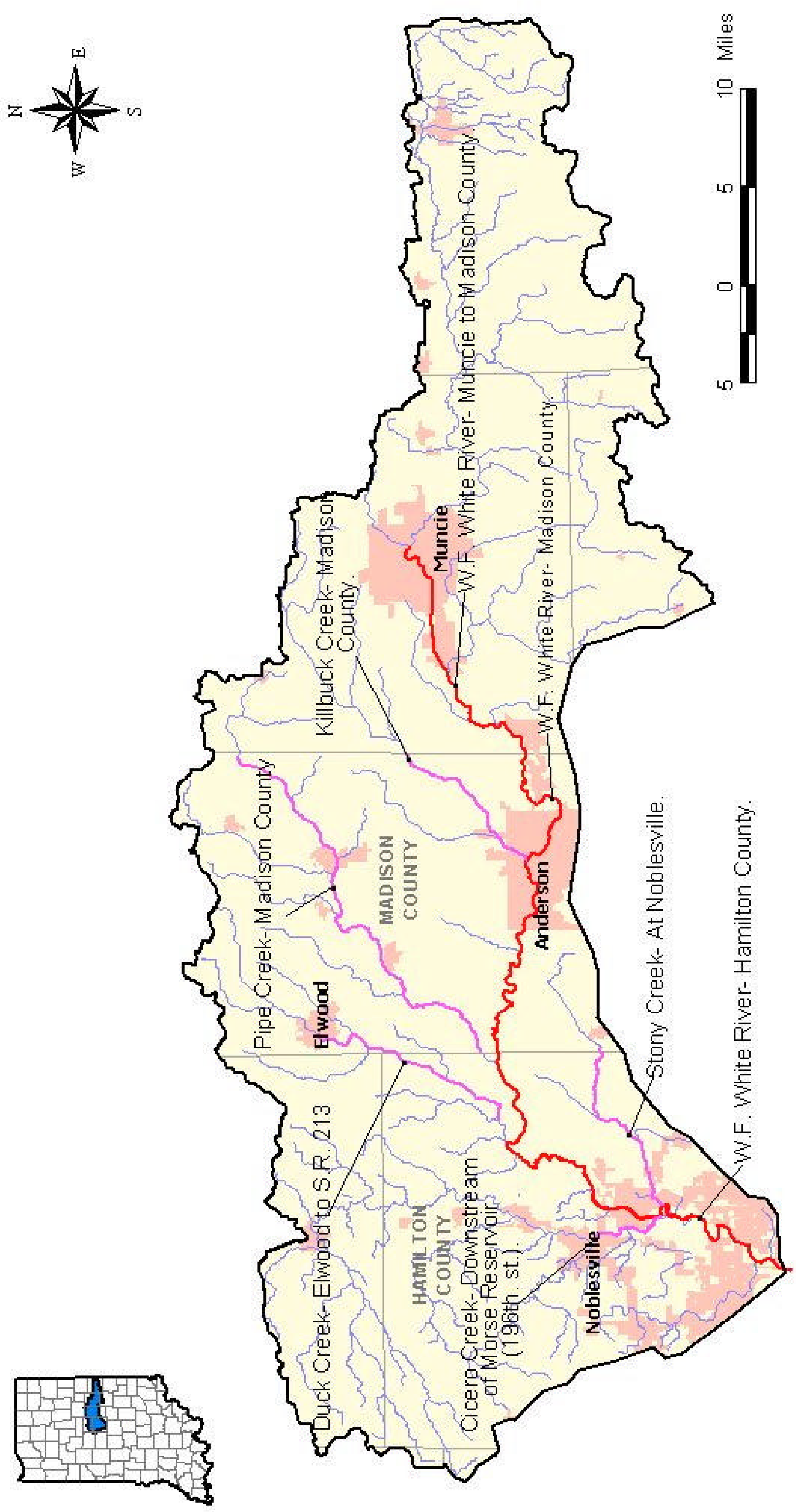


Figure 2. Waters in the WFWR watershed above the Hamilton-Marion County line that are listed for *E. coli*.

2.0 MODEL SELECTION

To meet the objectives defined for the WFWR TMDL, we believe that development of a comprehensive watershed model is necessary to represent the watershed. A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based calculations as input.

Receiving water models are composed of a series of algorithms applied to characteristics data to simulate flow and water quality of the waterbody. The characteristics data, however, represent physical and chemical aspects of a lake, river, or estuary. These models vary from simple 1-dimensional box models to complex 3-dimensional models capable of simulating water movement, salinity, temperature, sediment transport, and water quality.

2.1 Selection Criteria

In selecting an appropriate modeling platform to support management initiatives and development of TMDLs for the WFWR, the following criteria have been considered and addressed (expanding on classification of Mao, 1992):

- Technical Criteria
- Regulatory Criteria
- User Criteria

Technical criteria refer to the model's simulation of the physical system in question, including watershed and/or stream characteristics/processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. User criteria comprise the operational or economical constraints imposed by the end-user and include factors such as hardware/software compatibility and financial resources. The following discussion details considerations within each of these categories specific to the WFWR watershed.

2.1.1 Technical Criteria

Land use in the WFWR watershed includes row crop agriculture, older urban areas, and rapidly developing suburban areas. Different potential sources of pathogens are associated with each of these land use types (e.g., cattle, manure application, failing septic systems, combined sewer overflows, wastewater treatment plants, domestic pets) and each land use also has affected the natural hydrology of the watershed. Therefore the following considerations are critical to modeling the WFWR watershed.

- The model must be able to address a mixed land use watershed.
- Rainfall intensity and volume play an important role in pathogen loadings. The model must provide adequate time-step estimation of flow and not over-simplify storm events. It should provide accurate representation of rainfall events and resulting peak runoff.
- Different sources influence receiving waters in different ways and at different times (through different transport mechanisms). For example, surface runoff impacts waterbodies differently than direct stream contributions. The model must be capable of simulating these transport mechanisms.
- Representation of the potential impacts from combined sewer overflows during significant rainfall events, and associated loads to the WFWR, should be addressed.

2.1.2 Regulatory Criteria

A properly designed and applied model provides the source-response linkage component of the TMDL and enables accurate assimilative capacity assessment and allocation proposition. A river's assimilative capacity is determined through adherence to predefined water quality criteria. IDEM's surface water quality standards for the designated uses of the WFWR are as follows:

> "This subsection establishes bacteriological quality for recreational uses. In addition to subsection (a), the criteria in this subsection are to be used to evaluate waters for full body contact recreational uses, to establish wastewater treatment requirements, and to establish effluent limits during the recreational season, which is defined as the months of April through October, inclusive. *E. coli* bacteria, using membrane filter (MF) count, shall not exceed one hundred twenty-five (125) per one hundred (100) milliliters as a geometric mean based on not less than five (5) samples equally spaced over a thirty (30) day period nor exceed two hundred thirty-five (235) per one hundred (100) milliliters in any one (1) sample in a thirty (30) day period." [Source: Indiana Administrative Code Title 327 Water Pollution Control Board. Last Updated October 1, 2002]

In selecting the modeling system, consideration was given to the regulatory targets designated by IDEM for TMDL development. The selected model must be capable of simulating these water quality parameters using time-series simulation so that applicable averaging periods and peak levels can be determined and compared to numeric targets. The selected model must also be able to address seasonal variations in hydrology and water quality and critical conditions (i.e., periods when *E. coli* concentrations are at their highest) as required by TMDL regulations.

2.1.3 User Criteria

User criteria are determined by the needs, expectations, and resources of IDEM and the WFWR stakeholders. Although no modeling preferences have as yet been expressed by residents of the watershed, it is clear that they want to use the best approach possible. This is due to their desire to have waters that meet water quality standards in addition to the possibility that they might be asked to commit financial and other resources to reduce loads of *E. coli*. They want to know that efforts are being focused on the appropriate sources and the best science has been used to estimate the magnitude of necessary load reductions.

Furthermore, modeling software must be compatible with existing personal-computer-based hardware platforms, and due to future use for planning and permitting decisions, should be well-documented, tested, and accepted. Because IDEM is a public agency the software should also be publicly available and not proprietary. Another consideration is that future impairments might be identified in the WFWR watershed. Therefore another factor to consider is whether the chosen model can address these impairments.

From a resource perspective, the level of effort required to develop, calibrate, and apply the model must be commensurate with available funding, without compromising the ability to meet technical criteria. In addition to these primary criteria, the required time-frame for model development, application, and completion is important.

2.2 Review of Available Models/Approaches

The following models or technical approaches have been identified as potentially being appropriate for development of the WFWR *E. coli* TMDL.

2.2.1 Load Duration Curve

A simple approach to developing pathogen TMDLs is to calculate the desired loadings over the range of flow conditions expected to occur in the impaired stream. This approach is typically referred to as the "load duration curve" approach. Although the bare minimum elements of a TMDL can be addressed using the load duration curve approach, it has several weaknesses, as will be pointed out below.

The following steps are taken to use the load duration curve approach to develop TMDLs:

1. A flow duration curve for the gage site of interest is developed. This is done by generating a flow frequency table and plotting the points.
2. The flow curve is translated into a load duration (TMDL) curve. To accomplish this, the flow value is multiplied by the water quality standard and by a conversion factor. The resulting points are graphed.
3. A water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was taken. Then, the load is plotted on the TMDL graph.
4. Points plotting above the curve represent deviations from the water quality standard and the permissible loading function. Those plotting below the curve represent compliance with standards and represent adequate quality support for the appropriate designated use.
5. The area beneath the TMDL curve is the loading capacity of the stream. The difference between this area and the area representing current loading conditions is the load that must be reduced to meet water quality standards.

This approach helps to identify the issues surrounding the impairment and roughly differentiate between sources. Loads which plot above the curve in the flow regime defined as being exceeded 85 to 99 percent of the time (low flow conditions) are likely indicative of constant discharge sources. Those plotting above the curve over the range of 10 to 70 percent exceedance likely reflect wet weather contributions. Some combination of the two source categories lies in the transition zone of 70 to 85 percent exceedance. Those plotting above the curve at exceedances less than 10 percent or more than 99 percent reflect extreme hydrologic conditions of flood or drought.

There are two major weaknesses to the load duration curve approach. First, it does not allow a direct comparison to Indiana's *E. coli* standard because it does not generate an estimate of daily *E. coli* concentrations following implementation of the TMDL. Therefore it is impossible to make a comparison to the geometric mean or the instantaneous portion of the standard.

Secondly, the load duration curve approach provides very little information on the likely sources of pathogens. Unless the exceedances occur only during low flows (which is not the case in the WFWR) there will always be a question of the relative importance of the different sources. The load duration curve approach also provides no information on how the magnitude of loading differs by subwatershed.

2.2.2 Soil Water Assessment Tool (SWAT)

The Soil Water Assessment Tool (SWAT) model was developed by the U.S. Department of Agriculture, Agricultural Research Service. The model is intended to predict the impact of land management practices (e.g., vegetative changes, reservoir management, groundwater withdrawals and water transfer), on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT can analyze large watersheds and river basins (greater than 100 square miles) by subdividing the area into homogenous subwatersheds. The model uses a daily time step, and can perform continuous simulation for a period of one to 100 years. SWAT simulates hydrology, pesticide and nutrient cycling, erosion and sediment transport. It includes only a rudimentary capability to simulate pathogen loadings or instream concentrations.

SWAT is not considered an appropriate model for the WFWR TMDL because it is designed to address primarily agricultural watersheds and does not have much capability to simulate pathogen loadings or instream processes.

2.2.3. Generalized Watershed Loading Functions (GWLF) Model

The Generalized Watershed Loading Functions (GWLF) model can be used to estimate monthly nutrient loads from urban and agricultural watersheds, including septic systems (Haith et al., 1992). GWLF is based on simple runoff, sediment and ground water relationships combined with empirical chemical parameters. It evaluates streamflow, nutrients, soil erosion and sediment yield values from complex watersheds. Runoff is calculated with the NRCS curve number equation. Urban nutrient loads are calculated by exponential accumulation and wash-off functions. Nutrient loads from septic systems are calculated by estimating the per capita daily load from each type of septic system considered and the number of people in the watershed served by each type. GWLF can apply to relatively large watersheds with multiple land uses and point sources. It does not include the capability to simulate pathogen loadings or instream concentrations.

GWLF is not considered an appropriate model for the WFWR TMDL because it was never intended to evaluate bacteria issues. The stream flow component provides only monthly flows and therefore is inadequate to address the water quality standard which includes both a 30-day geometric mean and an instantaneous component. It is impossible to evaluate either portion of the standard with GWLF because daily concentrations of *E. coli* are not available. The average monthly concentration is irrelevant to the standard.

Furthermore, pathogen concentrations can vary dramatically according to daily streamflows so using a model that can only be calibrated to monthly volumes is inappropriate. It will be impossible to gage the performance of the model for individual storms (even if the monthly volumes look good), which is when the greatest loading of *E. coli* is likely to occur. GWLF also has a limited capability be calibrated to hydrology because the only hydrologic inputs are curve numbers and a groundwater discharge component; there are no “dials to turn” as there are in more advanced watershed models such as SWMM and HSPF so hydrologic calibration is limited.

Finally, GWLF lacks certain capabilities to address important factors related to pathogen loadings, such as dieoff rates and the buildup and washoff that occurs prior to and during storm events.

2.2.4 Water Quality Analysis Simulation Program (WASP)

WASP is a generalized framework for modeling water quality and contaminant fate and transport in surface waters. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using the WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.

The most recent version of WASP is WASP 6.1, which has been redeveloped in the Microsoft Windows (95/98/Me/NT/2000) environment to provide a graphical user interface for the development of input files. An advanced graphical post processor allows scientists and engineers to rapidly evaluate the model results. The user can plot field data versus predicted model results. Included in version 6.1 are the Thermal/Fecal Coliform models. The Thermal/Fecal Coliform model allows the user to simulate temperature using one of two approaches (full heat balance or equilibrium heat balance) as well as model the fate and transport of fecal coliform.

WASP is an advanced model and requires extensive input parameters. WASP provides the ability to evaluate pathogen concentrations at a fine spatial and temporal resolution. However, WASP is not a watershed model and it does not include a hydrology component. Therefore it must be run in tandem with a watershed model such as SWMM or HSPF to obtain information on daily watershed loads and flows. Resource considerations in addition to the problems associated with properly coupling WASP to a second model preclude the use of WASP for the WFWR TMDL.

2.2.5 Loading Simulation Program (C++) (LSPC)

LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, a dynamic watershed model (a re-coded version of EPA's Hydrological Simulation Program – FORTRAN [HSPF]), and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements. LSPC has been used successfully for development of pathogen TMDLs in Alabama; nutrient and/or dissolved oxygen TMDLs in Georgia, Tennessee, Kentucky, and Alabama; and metals TMDLs (using a derivative system, MDAS) in Alabama, Ohio, West Virginia, Virginia, and Arizona. LSPC is proposed for the WFWR watershed because it best matches the required technical, regulatory, and user criteria (see Table 1).

LSPC offers a number of advantages for use in pathogen TMDL development. These advantages include:

- LSPC provides storage of all geographic, modeling, and point source permit data in a Microsoft Access database and text file formats – thus data manipulation is efficient and straightforward.
- LSPC presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- LSPC can be easily linked to other models (advanced hydrodynamic and water quality models such as EFDC and WASP) in a modular fashion.
- LSPC can be easily modified to include additional features that are specific to the WFWR watershed - such features include the best management practices (BMP) module or other management strategies that can influence the potential runoff and water quality loading characteristics of the watershed.
- LSPC provides the user the ability to specify and develop queries to generate unique reports of model results.
- LSPC provides post-processing and analytical tools designed specifically to support TMDL development and reporting requirements (including a TMDL calculator).
- LSPC contains an archival mechanism for saving each and every model run (critical to support the administrative record for TMDL development and for model transfer between users).
- LSPC includes a customized GIS interface that does not require user-purchased software (critical for the public participation process/stakeholder input).
- LSPC allows users to evaluate future management alternatives and provide insight into where management or further monitoring might be useful.

Table 1. Evaluation of various models for developing *E. coli* TMDLs.

Criteria	Load Duration Curve	SWAT	GWLF	WASP	LSPC
Technical Criteria					
Mixed Land Use Watershed			$	N/A	$
Combined Sewer Overflows				$	$
Adequate Time Step Estimation of Flow		$		N/A	$
Includes *E. coli* as Output				$	$
Regulatory Criteria					
Output Can Be Directly Compared To WQS		$		$	$
Simulates Seasonal Differences in Hydrology/Loads	$	$		$	$
Provides Output for Critical Conditions	$	$		$	$
User Criteria					
Provides Detailed Information on Sources		$	$	N/A	$
Can Address Other Pollutants		$		$	$
Publicly available	$	$	$	$	$

$ Model addresses criteria

3.0 PROPOSED MODELING APPROACH

Development and application of the LSPC model to address the project objectives will involve a number of important steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Model Calibration and Validation
4. Model Simulation for Existing Conditions and Scenarios

3.1 Watershed Segmentation

Watershed segmentation refers to the subdivision of the entire WFWR watershed into smaller, discrete subwatersheds for modeling and analysis. This subdivision will primarily be based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries (from previous studies or for management considerations). Based on the availability of calibration data, the size of the watershed, and the scope of the project, an initial watershed segmentation has been made (Figure 3).

3.2 Configuration of Key Model Components

Configuration of the model itself will involve consideration of four major components: meteorological data, land use representation, hydrologic and pollutant representation, and waterbody representation. These components provide the basis for the model's ability to estimate flow and pollutant loadings. Meteorological data essentially drive the watershed model. Rainfall and other parameters are key inputs to LSPC's hydrologic algorithms. The land use representation provides the basis for distributing soils and pollutant loading characteristics throughout the basin. Hydrologic and pollutant representation refers to the LSPC modules or algorithms used to simulate hydrologic processes (e.g., surface runoff, evapotranspiration, and infiltration), and pollutant loading processes (primarily accumulation and washoff). Waterbody representation refers to LSPC modules or algorithms used to simulate flow and pollutant transport through streams and rivers.

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation. Meteorological data have been accessed from a number of sources in an effort to develop the most representative dataset for the WFWR watershed.

In general, hourly precipitation data are recommended for nonpoint source modeling (although in some cases, such as small, flashy, highly urbanized watersheds 15-minute data may be necessary). Therefore, only weather stations with hourly-recorded data have been considered thus far in the precipitation data selection process. Long-term hourly precipitation data from three National Climatic Data Center (NCDC) weather stations located within or near the WFWR watershed will be assessed for use in the watershed model. The NCDC rainfall data should sufficiently represent rainfall variability throughout the basin. Rainfall-runoff processes for each of the subwatersheds in the model will be driven by rainfall data from the selected stations (e.g., subwatersheds in the closest proximity to the Anderson station will be driven by this station's data).

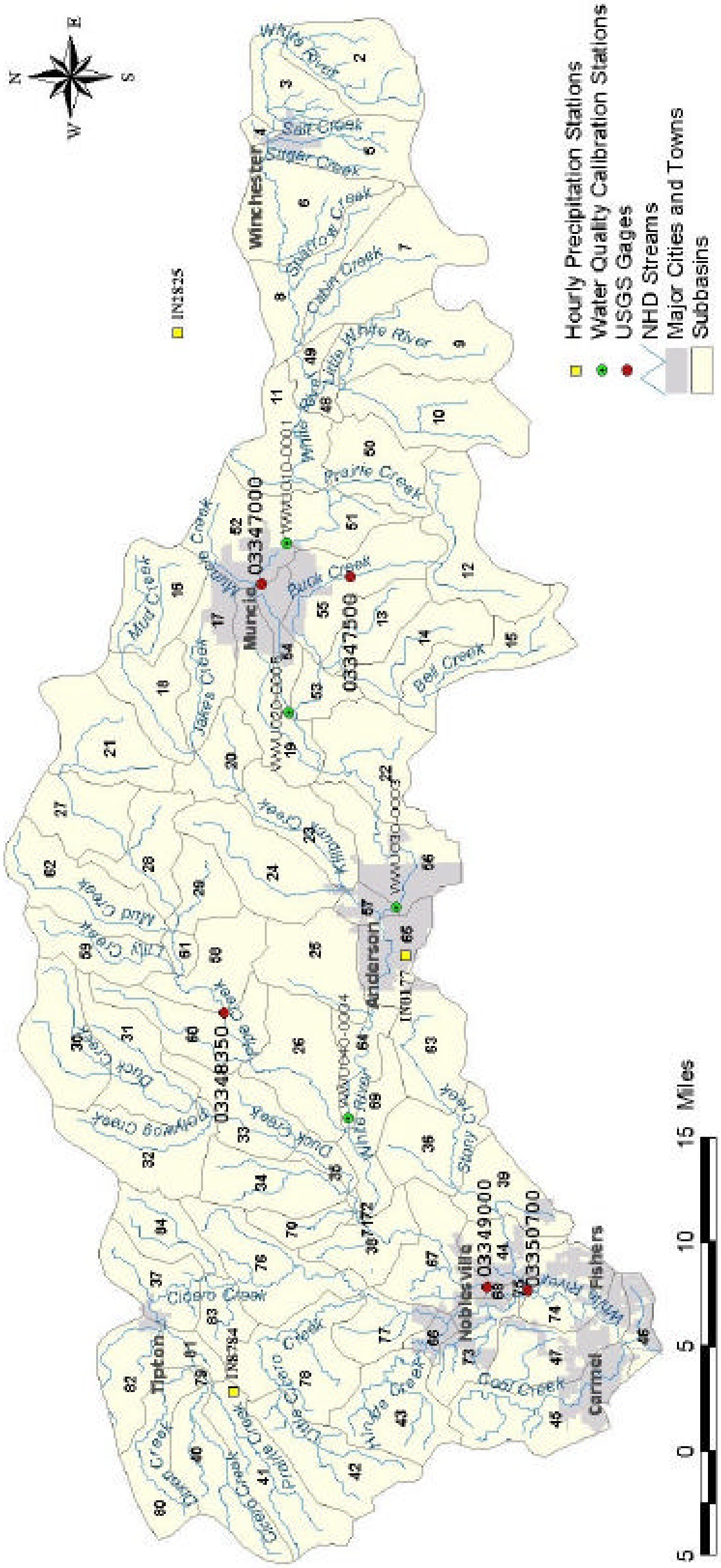


Figure 3. Watershed segmentation for the WFWR watershed.

The watershed model will require a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution will be provided by a land use coverage of the entire watershed.

As discussed in the Data Report (Tetra Tech, 2002) land use GIS data has been collected from two sources: (1) USEPA/USGS MultiResolution Land Characteristics (MRLC) Consortium data and (2) estimates of updated land use data for growing areas of the watershed from local officials and census data. data. It is expected that as many as 8 separate land use categories will be represented in the model. Selection of these land use categories will be based on the availability of monitoring data that can be used to characterize individual land use contributions and critical nutrient-contributing practices associated with different land uses. For example, multiple urban and agricultural categories will be represented independently (such as dairy/livestock, cropland, and sewered residential land), whereas forest and other natural categories will be grouped.

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division will be made for the appropriate land uses (primarily urban and possibly agricultural), in order to represent impervious and pervious areas separately. The division will be based on typical impervious percentages associated with different land use types from the Soil Conservation Service's TR-55 Manual. LSPC model algorithms simulating major hydrologic and pollutant loading processes will then be applied to each pervious and impervious land unit.

The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, will be used to represent hydrology for all pervious and impervious land units (Bicknell et al., 1996). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC will be required. These parameters are associated with infiltration, groundwater flow, and overland flow. The STATSGO Soils Database will serve as a starting point for designation of infiltration and groundwater flow parameters. For parameter values not easily derived from STATSGO, documentation on past HSPF applications will be accessed. Starting values will be refined through the hydrologic calibration process (described later in this section).

Pollutant loading processes for *E. coli* will be represented for each land unit using the LSPC PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules, which are identical to those in HSPF. These modules simulate the accumulation of pollutants during dry periods and the washoff of pollutants during storm events. Starting values for parameters relating to land-use-specific accumulation rates and buildup limits will be derived from the literature. These starting values will be refined through the water quality calibration process.

Modeling the entire WFWR watershed will require routing flow and pollutants through numerous stream networks. These stream networks connect all of the subwatersheds represented in the watershed model. Routing will require development of rating curves for major streams in the networks, in order for the model to simulate hydraulic processes. Hydraulic formulations typically estimate in-stream flow, water depth, and velocity using continuity and momentum equations. Streams will be assumed to be completely-mixed, one-dimensional segments with a trapezoidal cross-section. The rating curves will consist of a representative depth-outflow-volume-surface area relationship. In-stream flow calculations will be made using the HYDR (hydraulic behavior simulation) module in LSPC, which is identical to the HYDR module in HSPF. In-stream pollutant transport will be performed using the ADCALC (advective calculations for constituents) and GQUAL (generalized quality constituent simulation) modules.

3.3 Model Calibration and Validation

After initially configuring the WFWR watershed model, model calibration and validation will be performed. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. The calibration will be performed for different LSPC modules at multiple locations throughout the watershed. This approach will ensure that heterogeneities are accurately represented. The model validation will be performed to test the calibrated parameters at different locations or for different time periods, without further adjustment. Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for each modeled land use and pollutant will be developed.

Calibration and validation will be completed by comparing time-series model results to monitoring data. Output from the watershed model will be in the form of hourly/daily average flow and hourly/daily average concentrations for the modeled nutrients for each of the subwatersheds. Flow monitoring data are available at USGS flow gauging stations located throughout the watershed, while water quality monitoring data are available at fewer locations.

Hydrology will be the first model component calibrated, and it will involve a comparison of observed data from in-stream USGS flow gauging stations to modeled in-stream flow and an adjustment of key hydrologic parameters. Gaging stations representing relatively small subwatersheds in diverse hydrologic regions of the watershed will be used for calibration. The calibration year(s) will be selected based upon an examination of annual precipitation variability and the availability of observation data. The period will be determined to represent a range of hydrologic conditions: low, mean, and high flow conditions. Calibration for these conditions is necessary to ensure that the model will accurately predict a range of conditions for a longer period of time.

Key considerations in the hydrology calibration will include the overall water balance, the high-flow-low-flow distribution, storm flows, and seasonal variation. At least two criteria for goodness of fit will be used for calibration: graphical comparison and the relative error method. Graphical comparisons are extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy will primarily be assessed through interpretation of the time-variable plots. The relative error method will be used to support the goodness of fit evaluation through a quantitative comparison. A small relative error indicates a better goodness of fit for calibration.

After calibrating hydrology at multiple locations, independent sets of hydrologic parameters will be developed and applied to the remaining subwatersheds in the basin. A validation of these hydrologic parameters will be made through a comparison of model output to observed data at additional locations in the watershed. The validation locations are expected to represent larger watershed areas and essentially validate application of the hydrologic parameters derived from the calibration of smaller subwatersheds. Validation will be assessed in a similar manner to calibration.

After hydrology is sufficiently calibrated, water quality calibration will be performed. Modeled versus observed in-stream concentrations will be directly compared during model calibration. The water quality calibration will consist of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting pollutant loading and in-stream water quality parameters within a reasonable range. The objective will be to best simulate low flow, mean flow, and storm peaks at water quality monitoring stations representative of different regions of the basin (and different land uses, in particular). The TMDL monitoring stations will be particularly important in calibrating land use-specific pollutant loading parameters.

Adjusted water quality parameters will include pollutant buildup, washoff, and subsurface concentrations. Water quality calibration adequacy will be primarily assessed through review of time-series plots. Looking at a time series plot of modeled versus observed data will provide more insight into the nature of the system and is more useful in water quality calibration than a statistical comparison. Flow (or rainfall) and water quality can be compared simultaneously, and thus can provide insight into conditions during the monitoring period (dry period versus storm event). The response of the model to storm events can be studied and compared to observations (data permitting). Ensuring that the storm events are represented within the range of the data over time is the most practical and meaningful means of assessing the quality of a calibration. Due to the relative lack of water quality monitoring data, statistical comparisons will likely not be made. In the future, after collecting additional data, it may be beneficial to perform error analyses such as correlation (R-squared), Root Mean Square Error, and Mean Absolute Error.

Water quality parameters for the watershed model will be validated through a comparison of observed water quality data to modeled in-stream values. The validation will be performed, to the extent possible, at locations with sufficient water quality observation data located in areas draining large, mixed-land use portions of the watershed.

3.4 Model Simulation for Existing Conditions and Scenarios

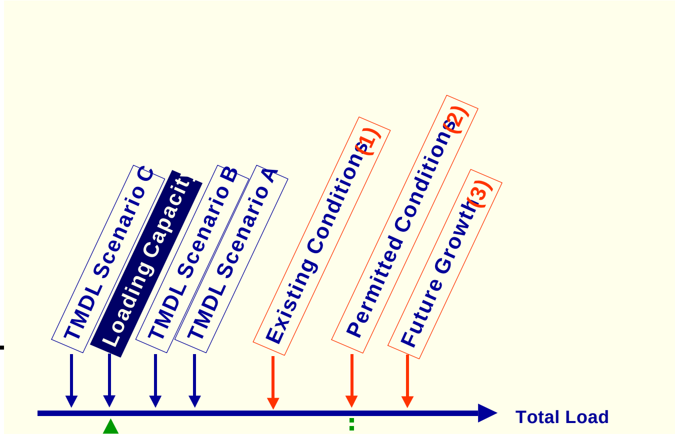
The fully calibrated model will be run for an extended time period to generate flow and pathogen loadings under a variety of conditions. Model output will be summarized to provide insight into average monthly, annual, and seasonal loads. The existing conditions represent the starting point for TMDL analyses. The allocation analysis is typically performed by following discrete steps, as illustrated in Figure 4.

Step 1: Application of the Model to Existing Conditions
This application forms the current condition that is compared to available monitoring information for model testing and calibration.

Step 2: Application of the Model to Existing Conditions with Point Sources at Permit Limits
This application forms the baseline condition which will be reduced to meet the allowable load. The point sources are set at permit conditions using the permitted flow and mean daily concentration allowed for in the permit. If no permitted flow is available, the design flow or historic observed flow can be used.

Step 3: Application of the Model to Future Conditions
When future growth is considered, it can be added to the nonpoint and/or the point source loading contributions.

Figure 4. Steps in the allocation process.



Step 4: Develop and Test Allocation Scenarios
Working from the baseline condition (Step 2, or Step 3 if future growth is considered), and considering the results of the source-response analysis, sample allocation scenarios are developed and applied. These scenarios are shown as A, B, and C in Figure 1. The results of each scenario are compared with the applicable water quality standard. The scenarios are adjusted until water quality standards (or loading capacity) are achieved.

Step 5: Select Final TMDL Scenario
The state selects the final TMDL scenario and results are processed to provide the required TMDL elements. Data processing is needed to provide the annual and monthly load for each category stipulated in the TMDL. The final scenario model input and output file is saved for the administrative record.

3.4.1. Margin of Safety

Section 303(d) of the Clean Water Act and USEPA's regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be implicitly incorporated into conservative assumptions used to develop the TMDL or added as a separate explicit component of the TMDL (USEPA, 1991).

An explicit margin of safety will be incorporated into the WFWR TMDL by reducing the water quality target to provide additional assurance. The *E. coli* target will be set five percent lower than the numeric criteria in water quality standards.

4.0 REFERENCES

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